7 Sediment Quality Thresholds

The overall objective of the Fox River RI/FS is to evaluate corrective actions that may be applied to contaminated sediment within the Lower Fox River and Green Bay. Those corrective actions will be based on the projected reductions of risk to human health and the environment. To that end, the BLRA in Sections 5 and 6 defined the current (or baseline) human health and ecological risks associated with the chemicals of concern; PCBs, mercury, and DDE. Of those, PCBs were identified as the principal component of risk to human health and the environment. To facilitate the selection of a remedy that will result in a decrease in those risks, it is necessary to establish a link between levels of PCBs toxic to human and ecological receptors, and the principal source of those PCBs, the Lower Fox River and Green Bay sediment.

The final chapter role of the risk assessment for the Lower Fox River and Green Bay provides that link between risk in human, birds, mammals and fish by estimating safe thresholds of PCBs in sediment. This section details the methods by which safe thresholds in sediment can be determined. Mathematical bioaccumulation models are used to estimate threshold concentrations of PCBs in sediments that, below which, risks should not occur for the intended receptors. Called sediment quality thresholds (SQTs), these numeric and site-specific values are developed for each pathway and receptor identified as important by the response agencies of the Lower Fox River and Green Bay (e.g., sport fishing consumption, bald eagles). The SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level. SQTs are used to evaluate harmful levels of contaminants that must be addressed, what levels of those chemicals can be safely left behind, and which remedial option offers the best risk reduction. From the array of PCB-SQTs for specific human health and ecological receptors, the response agencies can evaluate risk reduction and select cleanup standards, or remedial action levels, as a part of a feasibility study. The final selection of the remedial action levels carried forward in the FS is a policy decision left to the response agencies, and the array of PCB-SQTs are principal components of justifying these action levels.

Bioaccumulation modeling is an established part of cleanup programs in the Great Lakes (Pelka, 1998). The *Work Plan for Data Management, Remedial Investigation/ Feasibility Study, and Baseline Human Health and Ecological Risk Assessment for the Lower Fox River and Green Bay* identified the use of dynamic food web modeling (the FRFood Model) to establish risk relationships between sediment concentrations of nonionic organic chemicals and concentrations of those compounds in fish tissue.

The objective of this section then is to develop that array of PCB-SQTs by:

- Estimating PCB-SQTs that would not result in accumulations to fish tissues at levels that exceed acceptable human health risk levels (cancer risks of 10^{-4}, 10^{-5}, and 10^{-6}, and noncancer risk of a hazard index equal to 1.0; and

- Estimating PCB-SQTs that would not result in unacceptable risks to ecological receptors (e.g., NOAEC, LOAEC).

7.1 Food Web Models for the Lower Fox River and Green Bay

For the overall Remedial Investigation and Feasibility Study, computer models have been developed to assist in the selection of cleanup action levels for PCBs, and for the evaluation of PCB fate and transport into the future. These include:

- The *Whole Lower Fox River Model* (wLFRM) is used to simulate the fate and transport of PCBs in the water and sediments in the Fox River.

- The *Green Bay Toxics* model (GBTOXe) simulates the fate and transport of PCBs in water and sediment in Green Bay.

- The *Fox River Food* (FRFood) is used to estimate PCB concentrations in the food webs leading to forage fish (e.g., shiners, gizzard shad, alewife), benthic fish (e.g., carp), and game fish (perch, walleye) in the river and lower Green Bay.

- The *Green Bay Food* (GBFood) bioaccumulation model receives input data from both wLFRM and GBTOXe and is used to estimate PCB concentrations in the food webs leading to brown trout and walleye Green Bay.

A complete description of all the models used in the RI/FS is given in the companion document *Model Documentation Technical Report for the Lower Fox River and Green Bay* (RETEC, 2002c). The rest of this section focuses on the bioaccumulation models used to develop the Sediment Quality Thresholds.

Numerous aquatic food chain bioaccumulation models have been developed to estimate transfer of hydrophobic contaminants from sediment and water to aquatic biota. The simplest of these models are the ratios of observed concentrations of contaminants in target organisms to observed concentrations in sediment or water: bioaccumulation factors (BAFs), or biota/sediment accumulation factors (BSAFs). While simple in their approach, BSAFs have been shown to provide reasonable accuracy in the prediction of fish tissue concentrations in areas where sufficient data are available (Boese and Lee, 1992). BSAFs have been used to establish cleanup goals for Saginaw River, Michigan and Manistique Harbor, Michigan (Pelka, 1998). However, BSAFs are limited because they are area-specific to the system and organisms, they cannot be used to predict contaminant uptake and distribution through the food chain, and they have limited ability to predict fish concentrations under future conditions.

Uptake models that predict the movement of contaminants from sediments into and through a given food web are often termed bioenergetic models (Boese and Lee, 1992). As compared to BSAFs, bioenergetic models are more mathematically sophisticated, require a greater understanding of the system ecology, and when constructed properly, these models can accurately predict contaminant distribution (Pelka, 1998). Examples of these models include the bioconcentration models of Veith *et al.* (1979) and Gobas (1993), the bioaccumulation models by Thomann (1989) and Thomann and Connolly (1984), the biomagnification models by Bierman (1990) and Clarke and McFarland (1991), and the fugacity-based model by Campfens and Mackay (1997).

For the Lower Fox River and Green Bay, two models have been developed for use in the RI/FS: the Fox River Food (FRFood) and Green Bay Food (GB Food) web. These are discussed in more detail below.

7.1.1 FRFood Model

The FRFood model was developed based on the algorithms of the Gobas model (1993). FRFood is used in the RI/FS to model PCB concentrations in fish within the Lower Fox River and lower Green Bay (zones 1 and 2), and to develop the PCB-SQTs. The Gobas model was selected for several reasons including:

- The model was developed for Great Lakes food chains and has been previously validated using both Lake Ontario and Green Bay PCB and food web data.

- EPA made extensive use of the Gobas model to derive bioaccumulation factors, bioconcentration factors, and food chain multipliers in the development of the Great Lakes Water Quality Initiative (GLWQI) criteria (EPA, 1993b, 1994a).

- The Gobas model was used in the 1996 RI/FS for the Lower Fox River and found to yield reasonably good results between predicted and measured fish tissue PCB concentrations (GAS/SAIC, 1996).

- A modified version of the Gobas model was used for the Ecological Risk Assessment for the Sheboygan River, Wisconsin, and also found reasonable similarity between predicted and measured PCB levels in fish (EVS, 1998)

- The Gobas algorithms were used to project future PCB concentrations in fish for the Hudson River (EPA, 2000a).

The Gobas model has seen the most widespread use in the Great Lakes area. In 1993, Gobas introduced his methods by modeling a food web in Lake Ontario. He compared predicted levels of PCBs in a Lake Ontario food web to published observed data (Oliver and Niimi, 1988), and found that predicted versus observed PCB concentrations were within a factor of five for all organisms. The model was particularly accurate in determining PCB levels in higher trophic levels (all fish), where predicted levels of PCBs versus observed differed by less than a factor of two.

Both the Gobas model (1993), and a similar model constructed by Thomann (1989) and Thomann *et al.* (1992) have gained general scientific acceptance and are now being used in scientific and regulatory applications to predict concentrations of hydrophobic organic contaminants in aquatic food webs (Burkhard, 1998). Burkhard (1998) recently reviewed the predictive capabilities of these two models compared to field-collected fish data from Lake Ontario and concluded that the Gobas model provided slightly better predictions.

While the Gobas model was developed specifically for application in lake systems, the mathematical relationships have been successfully applied to predicting fish tissue concentrations in some river systems. As noted above, the 1996 RI/FS for the Fox River found good correlation between predicted and observed fish tissue concentrations. Likewise, a good fit between predicted and observed fish tissue concentration was observed when the model was used to describe the bioaccumulation of PCBs in Hudson River ecosystems (EPA, 2000a), and the Sheboygan River (EVS, 1998). In part, this may be because the lock and dam system on the Fox and Hudson rivers creates a series of large “pools” that behave more like reservoir or lake-like systems (e.g., Little Lake Butte des Morts).

The Gobas model assumes that equilibrium steady states exist between water and plankton, and between sediment and benthic invertebrates. Lipid-normalized phytoplankton and zooplankton concentrations are assumed to equal organic carbon-normalized water concentrations. Lipid-normalized benthic invertebrate concentrations are estimated to equal organic carbon-normalized sediment concentrations. Non-equilibrium steady-state concentrations in fish are calculated assuming mass balance where contaminant uptake from diet and gill ventilation is equal to loss through gill ventilation, egestion, metabolic breakdown, and dilution by growth.

Since 1993, several improvements/additions to the Gobas model have been suggested, including a time-dependent response to changes in PCB levels which incorporated age classes to organisms (Gobas *et al.*, 1995) and a more sophisticated model to describe bioaccumulation of PCBs in zooplankton and benthic invertebrates (Morrison *et al.*, 1996). Morrison *et al.* (1996) improved modeled zooplankton and benthic invertebrate bioaccumulation by considering PCB intake from diet (by filter feeding and consumption of detritus) and gill ventilation, and loss through gill ventilation, egestion, metabolic breakdown, and dilution by growth. A verification of an entire aquatic food web using the 1993 Gobas model and improved zooplankton and benthic invertebrate model was published in 1997 (Morrison *et al.*, 1997). All verification attempts found that estimated concentrations of PCBs typically fell well within an order of magnitude of observed results. However, these modifications were not incorporated into FRFood due to: 1) the lack of site-specific input parameters necessary to implement those modifications, and 2) the generally good agreement between predicted and observed PCB fish tissue concentrations for FRFood.

A discussion of the selection, development, calibration, validation, and application of the FRFood Model is provided in the Model Description Memorandum.

7.1.2 GBFood Model

The GBFood bioaccumulation model is a mathematical description of contaminant transfer within the Green Bay food web. The food web is comprised of the primary energy transfer pathways from the exposure sources (sediment and water) to the fish species of interest. These pathways include: chemical uptake across the gill surface, chemical uptake from food and chemical losses due to excretion and growth dilution. The mathematical descriptions are generic (common to all aquatic food webs) and were updated as part of this RI/FS.

GBFood is based on the work of Connolly *et al.* (1992) which incorporated algorithms from Thomann (1989) and Thomann *et al.* (1992). GBFood will be used in the FS to estimate fish tissue concentrations based on 100-year projected sediment concentrations for different remedial alternatives. GBFood is not designed to estimate sediment PCB concentrations from fish tissue concentrations, and thus is not being used to develop PCB-SQTs. A description of the GBFood Model dietary assignments and model validation are contained in the Model Documentation Technical Report (RETEC, 2002c)

7.2 FRFood Model Food Web Review and Dietary Assignments

FRFood is constructed from the mathematical relationships between sediment, water, phytoplankton, zooplankton, and contaminant transfer factors to prey and predatory fish that were originally defined by Gobas (1993). The construct of the model, the input parameters, and the application of the model are documented in the *FRFood Users Guide* (RETEC, 2002d).

As note above, the Gobas algorithms were selected to develop the FRFood model in part because of the accuracy observed in predicting fish tissue concentrations in the 1996 RI/FS for the river above the De Pere dam (GAS/SAIC, 1996). While the 1996 food web model provided a reasonable degree of accuracy in predicting fish tissue concentrations, it was necessary to re-examine the food web relationships for use in the FRFood Model because the 1996 food web does not accurately reflect predator/prey relationships in the river and Green Bay.

A key assumption of the previous RA for the Lower Fox River was that the food web was principally based on sediment-dwelling insects (GAS/SAIC, 1996). In 1996, the benthic invertebrates selected for modeling included oligochaetes and chironomids, based upon their predominance in previous benthic analyses done within the Fox River system (WDNR, 1993), and on the work by Call *et al*. (1991), and the mayfly *Hexagenia*, based upon mayfly presence in both the reference sites for the WDNR (1993) study and the Call *et al.* (1991) study.

In the 1996 Lower Fox River bioaccumulation model, carp was selected as the benthic fish species for the model based upon the fact that it is the dominant benthic feeding fish found within the Lower Fox River system. In addition, carp PCB body burden data were measured as part of the mass balance study, and available information concerning size, lipid content, and diet were reviewed. Carp were assigned oligochaetes and chironomids as principle forage, but also assigned a smaller fraction of mayflies and zooplankton. Walleye were selected as the top piscivorous species for the model, based upon relative abundance, their importance to Lower Fox River anglers, and availability of data for modeling. A second key assumption of the 1996 model was that yellow perch are the preferred prey species for walleye (Ney, 1978; Ryder and Kerr, 1978). In the 1996 model, yellow perch fed predominantly on benthic invertebrates (Ney, 1978), while walleye fed principally on yellow perch, small carp, and a smaller fraction of emergent *Hexagenia* larvae.

The FRFood Model was designed to accurately reflect food web interactions using information on receptors in the river and Green Bay. Two food web models were used to describe the food web in the Lower Fox River and southern Green Bay: one for above the De Pere dam and one for below the dam (Green Bay zones 1 and 2). The revised food webs were discussed and presented in Section 6 (see Figures 6-1 through 6-3). Selection and documentation of the important food webs for all of the Fox River and Green Bay are given in WDNR Technical Memorandum 7c (WDNR, 2001). The principal changes from the 1996 food web model is the shift from a primarily benthic-based food chain to a food web that equally includes both benthic and pelagic uptake routes. In addition, other fish species (e.g., alewife, gizzard shad) and year classes for yellow perch, alewife, and carp were added. An additional change to the Lower Fox River food web was the exclusion of *Hexagenia*, as it is generally not found in the Lower Fox River and Green Bay (WDNR, 1995).

Once the food webs were identified, a literature search was conducted to develop a range of values for diet composition (species and percent prey based on weight or volume of prey), weight, and lipid content. The range of values are presented in Table 7-1.

7.3 FRFood Model Calibration

The calibration for the FRFood Model was run using site-specific total PCB data for sediment and water as well as site-specific dietary relationships and lipids. Total PCB-SQTs were estimated for the following reasons: 1) total PCBs are used in the risk assessment to encompass all observed toxicity, including that from the dioxin-like coplanar congers as well non-coplanar PCB molecules; 2) transfer factors for specific PCB co-planar congeners between the various media (sediment, pore water, surface water, phytoplankton, zooplankton, prey fish, predator fish, birds, humans) are not well supported in the FRDB or scientific literature; and 3) remedial actions have been based to date on total PCBs, and not congener-specific cleanup levels (e.g., Deposit N, SMU 56/57 demonstration projects).

Calibration of FRFood was based upon comparing predicted versus actual fish tissue PCB concentrations, and is discussed in detail in the FRFood Model Documentation Memorandum (RETEC, 2002e), and in the *FRFood User's Guide* (RETEC, 2002d). Generally, sediment and water concentrations derived from the FRDB (discussed in Section 6.4) were used as inputs to the model for each reach. Dietary inputs for the food web species were generally based on average consumption, but modified as necessary for calibration purposes within the range of parameters specified in Table 7-1. Lipid concentrations for fish were also treated as a calibration variable. In general, the arithmetic average concentration on a reach-specific basis for each species selected. FRFood Model output was then compared to actual measured fish concentrations from Little Lake Butte des Morts, Little Rapids to De Pere, De Pere to Green Bay (Green Bay Zone 1), and Green Bay Zone 2. There were only sufficient data for these four areas to check the model.

The model evaluation metrics that were used to determine if the FRFood Model was an effective tool for estimating PCB-SQTs for the FS were those used in the Green Bay Mass Balance Study and agreed upon by the WDNR in cooperation with the Fox River Group of companies (Limno-Tech, 1998). The goals are to achieve agreement of ±30 percent between model predictions and observations for water and sediment, and plus or minus one-half order of magnitude for fish. Input parameters, both physical and dietary, for each species and each of the areas are presented in Tables 7-2 through 7-5.

Sediment-weighted average concentrations (SWAC) were used as input to the FRFood. The surface sediment interpolated total PCB concentrations (I_d) from the bed maps (see Section 2.3) were selected over non-interpolated total PCB sediment concentrations (average or 95th UCL), because between river reaches, the spatial degree of PCB analysis conducted on sediment in each area varied. Using the surface SWAC normalized total PCB concentrations between river reaches.

PCB concentrations inputs for water were based upon the filtered fraction of water samples collected, and reported in the FRDB. The filtered fraction represents the PCB fraction that is available for uptake; i.e., not bound up with the particulate or organic (i.e., phytoplankton or zooplankton) fractions in the water column. Using the filtered water as an input ensured that the phytoplankton/zooplankton component was not counted twice in the model calibration. Details of this analysis are covered in the FRFood Model Documentation Memorandum (RETEC, 2002e).

The comparison of FRFood Model output to the mean and 95% UCL whole fish tissue concentrations collected by reach are shown in Table 7-6. The starting sediment and water concentrations are boxed and bolded. Calibration of the FRFood Model indicated that all predicted fish tissue concentrations were within one-half order of magnitude of observed concentrations of total PCBs, except for yellow perch in the Little Lake Butte des Morts Reach. However, within this reach data were only available for one fish. All other predicted fish concentrations were within a factor of two compared to the observed tissue concentrations of total PCBs, except for common and emerald shiners in Green Bay Zone 1. Importantly, the predicted shiner concentrations in this zone were only 14 percent more than the measured concentrations in golden shiner. Based upon these observed/predicted results compared to the model evaluation metrics, the Lower Fox River bioaccumulation model is judged suitable for use in estimating PCB-SQT concentrations within the Lower Fox River. These results indicate that the FRFood model meets the metrics goal of achieving agreement in predicted and observed fish tissue concentrations to within plus or minus one-half order of magnitude for fish.

7.4 Determination of Sediment Quality Thresholds

7.4.1 Estimating Sediment-to-water Ratios

To calculate a PCB-SQT from a fish tissue concentration, it was necessary to identify a generalized term relating the concentration of total PCBs in filtered water relative to that found in the sediments. The same water and sediment data used to calibrate the mass balance for the Fox River were used to estimate this term. These data are shown in Table 7-7, and represent the minimum, maximum, and average values computed for 1989 through 1990 calibration period. For the Lower Fox River, the data suggest that the non-particulate water PCB concentration is between 10^{-6} and 10^{-7} of the bedded sediment concentration. For the De Pere to Green Bay Reach (Zone 1), the value lies between 10^{-4} and 10^{-6}. As a general term for developing the river SQTs, a value of 10^{-6} was used to estimate SQTs.

The estimated sediment-to-water ratios for Zone 2 is complicated by the fact that approximately 70 percent of the water in Zone 2 (Long Tail Point to Point Sable) is comprised of water from the Lower Fox River (Brazner and Beals, 1997). To estimate the sediment/water resuspension rates for PCBs, the GBTOX mass balance model was run using zero PCB loading from the Lower Fox River. Given no loads from the Fox River, the average water column concentrations ranged between 10^{-7} to 10^{-5} of the interpolated sediment concentrations. Given these estimates, a 10^{-6} term is also applicable to Zone 2 sediments.

Because of the uncertainty associated with the sediment-to-water ratio, SQTs may differ by an order of magnitude. For example, walleye NOAEC SQTs based on a sediment-to-water ratio of 10^{-5} are eight times less than an SQTs based on a sediment-to-water ratio of 10^{-6} and 25 times less than an SQT based on a sediment-to-water ration of 10^{-7}.

7.4.2 Human Health Sediment Quality Thresholds

Human health PCB-SQTs were developed for recreational anglers and high-intake fish consumers at both the 10^{-5} risk level and at a hazard index of 1.0 for walleye, perch, and carp. SQTs were estimated for reasonable maximum exposure and the central tendency exposure scenarios. SQTs associated with cancer risk levels of 10^{-4} and 10^{-6} are one order of magnitude below, and one order of magnitude higher than the SQTs for the 10^{-5} risk level.

To estimate the human health PCB-SQT, risk-based fish concentrations (RBFCs) were developed for PCBs in fish fillets (see Section 5.9.9). Since these RBFCs are expressed as concentrations of PCBs in fillets, it was necessary to convert RBFCs for the fish fillet to RBFCs for whole body fish. Based on data obtained from the literature, the ratio of PCB concentrations in fillet to whole body can be estimated:

$$C_{fish-f} = a_{f-wb} \cdot C_{fish-wb}$$

where:

$C_{fish\text{-}f}$	=	concentration of PCBs in fish fillet (μg/kg-fillet),
$a_{f\text{-}wb}$	=	ratio of concentrations in fish fillet to concentrations in whole body of fish (kg-fish/kg-fillets), and
$C_{fish\text{-}wb}$	=	concentration of PCBs in whole body of fish (μg/kg-whole body).

Once whole body RBFCs for total PCBs were obtained, these concentrations were used as inputs to the FRFood Model, which then output PCB concentrations in sediment that represent PCB-SQTs.

To calculate fillet-to-whole body ratios, both site-specific data and literature-derived ratios were examined. Table 7-8 summarizes ratios of PCB concentrations for fillet and whole body for a number of different fish species. For the Lower Fox River, data were available in the FRDB to estimate fillet-to-whole body ratios for walleye (0.17), carp (0.53), white bass (0.44), and white sucker (0.48). For perch, there were insufficient data to estimate a ratio specific to perch, but the walleye ratio was deemed applicable. Perch are from the same family as walleye (*Percidae*) and have similar lipid values. Table 7-8 also presents the ratios from other studies. The ratios range from 0.04 for perch to 1.0 for brown trout. The perch value of 0.04 from Parkerton (1993) for fish collected at Lake Erie and the data used to develop this ratio were not available for review. Thus, the perch value of 0.04 was not used. There is variability within the same species, with ratios ranging from 0.57 to 1.0 for brown trout; 0.59 to 0.89 for coho salmon; 0.34 to 0.68 for rainbow trout; and 0.09 to 0.17 for walleye.

Table 7-9 presents the PCB-SQTs associated with a risk level of 10^{-5} and a hazard index of 1.0 for carp, walleye, and perch for the Lower Fox River. These values ranged between 11 μg/kg-sediment PCBs for the high-intake fish consumer eating carp under an RME scenario, to 1,128 μg/kg for a recreational angler eating perch under a CTE scenario. It is important to note that Table 7-9 presents the SQTs associated with a target rate of 10^{-5}; the SQTs associated with cancer ratios of 10^{-6} and 10^{-4} are an order of magnitude lower, or higher, respectively. All three ranges of cancer risks are carried forward into the Feasibility Study to be evaluated as part of the action level selection process, and for the evaluation of remedial alternatives.

7.4.3 Ecological Sediment Quality Thresholds

Total PCB-SQTs protective of ecological receptors were derived from the toxicity reference values listed in Table 6-5 of the ecological risk assessment. The total PCB fish Toxicity Reference Value (TRV) for the various receptors were used as inputs to the FRFood Model, and then back-calculated to yield the PCB-SQT. Total PCB-SQTs were directly derived from the TRVs for fish survival and reproduction and for mink reproduction and kit survival based upon total PCB concentrations in fish as part of their diet. The fish species selected for PCB-SQT determinations were walleye and carp, because they are the highest trophic level pelagic and benthic fish present in the river. Sediment quality thresholds that are protective of walleye and carp should also be protective of other fish species present.

For piscivorous and carnivorous birds, TRVs were based on egg or whole body concentrations. Therefore, it was necessary to derive site-specific biomagnification factors (BMFs) to determine what were safe concentrations in fish, their sole or primary prey. For bald eagles, carp were assumed to be the primary prey, and for both tern species and double-crested cormorants, alewife were assumed to be the primary prey. Total PCB concentrations in these bird species (egg or whole body) were compared to primary prey concentrations within the same reach to derive species-specific BMFs. The BMF was calculated by dividing the bird receptor egg or whole body concentration by the fish concentration. To facilitate the calculation of the BMF, it was conservatively assumed that the diet of these bird species was 100 percent alewife, and that all of the PCBs are transferred from fish to eggs. These BMFs were then applied to the total PCB TRVs for birds in order to convert these bird tissue TRVs into fish tissue TRVs. While limitations of the BMF model were discussed previously, there are no kinetic bioaccumulation models that have been validated for fish-to-bird contaminant transfers. The BMF model, used with site-specific data and within this context, is the best approximation of bird contaminant exposure. BMFs and estimated threshold fish tissue concentrations for effects to reproduction and embryo physiology are given in Table 7-10.

Total PCB sediment quality thresholds for fish, birds, and mink are given in Table 7-11. The PCB-SQTs range from a low of 24 μg/kg that is protective of mink reproduction and kit survival, to a high of 5,231 μg/kg that corresponds to a LOAEC for common tern deformity.

7.5 Section 7 Tables

Section 7 tables follow this page and include:

Table 7-1 References Reviewed for Potential Input Parameter to the Lower Fox River Bioaccumulation Model

Organisms	Dietary Composition (based on weight or volume)	Whole Fish Lipid Content (%)	Weight (kg)
Plankton			
Zooplankton		5 (Gobas, 1993)	0 (Campfens and Mackay, 1997)
Benthic Organisms			
Oligochaetes		1 (Campfens and Mackay, 1997)	0.0001 (Campfens and Mackay, 1997)
Chironomids		2 (Zaranko *et al.* , 1997)	
Fish			
Rainbow Smelt	25%–100% zooplankton, 0%–25% alewife (Mills *et al.* , 1995; Price, 1963)	1.7–9.8 (site-specific data)	0.085 (Seagrant web page)
Gizzard Shad	10%–70% zooplankton, 10%–90% algae, 10% benthic invertebrates (Muth and Busch, 1989; Kolok *et al.* , 1996; Exponent, 1999)	2.5–19.0 (site-specific data)	0.025 (Levine *et al.* , 1995)
Emerald Shiner	90% zooplankton, 5% algae, 5% chironomids (Muth and Busch, 1989)	5.1–6.2 (site-specific data)	
Carp			
YOY[1]	14%–100% benthic invertebrates, 10%–60% plankton (Weber and Otis, 1984; Exponent, 1999)		0.00629 (Weber and Otis, 1984)
adults	14%–100% benthic invertebrates, 25%–45% plankton (Scott and Crossman, 1973)	0.8–25.4 (site-specific data)	1.4–6.8 (Scott and Crossman, 1973)
Alewife			
YOY	20%–90% copepods, 10%–80% cladocerans (Hewett and Stewart, 1989; Urban and Brandt, 1993)		avg. = 0.00071 (Flath and Diana, 1985)
adults	25%–93% plankton, 7%–20% benthic invertebrates (Gobas *et al.* , 1995; Hewett and Stewart, 1989; Exponent, 1999)	2.5–17.0 (site-specific data)	0.056 $\pm$ 0.007 (Hewett and Stewart, 1989)
Perch			
YOY and adults	40%–100% benthic invertebrates, 60% plankton (Scott and Crossman, 1973; Weber and Otis, 1984; Exponent, 1999; Carlander, 1997a)	2.2–6.1 (site-specific data)	0.01–0.588 (Wells and Jorgenson, 1983)
Walleye			
YOY	0%–96% rainbow smelt, 0%–78% gizzard shad, 0%–20% emerald shiner, 0%–80% white perch, 0%–29% yellow perch, 0%–28% white sucker, 0%–24% benthic invertebrates (Wolfert and Bur, 1992; Exponent, 1999; Carlander, 1997b)		0.04 (Magnuson and Smith, 1987)
adults	10% plankton, 14%–24% benthic invertebrates, 12%–100% alewife, 0%–76% rainbow smelt, 0%–74% gizzard shad, 0%–1% sculpin, 0%–38% white sucker, 0%–44% yellow perch, 0%–23% small mouth bass (Magnuson and Smith, 1987; Wolfert and Bur, 1992)	0.4–23.2 (site-specific data)	2.3 (site-specific data)

Note:

[1] YOY - Young-of-the-year.

Table 7-2 Inputs to the FRFood Model for Model Calibration in Little Lake Butte des Morts Reach

A. Diet

Prey	Receptors							
	Shiner Species Muth & Busch, 1989	Gizzard Shad Muth & Busch, 1989; Kolok *et al.*,	Yellow Perch YOY Carlander, 1997a; Scott & Crossman,	Yellow Perch Adult Carlander, 1997a	Carp YOY Weber & Otis, 1984	Carp Adult Scott & Crossman, 1973	Walleye YOY Carlander, 1997b; Wolfert & Bur,	Walleye Adult Wolfert & Bur, 1992; Magnuson & Smith, 1987
Phytoplankton	0.7	1		0.3	0.3			0.1
Zooplankton	0.2		0.9	0.4	0.4	0.45	0.05	
Chironomids	0.1		0.1	0.3	0.3	0.35	0.1	0.2
Oligochaetes						0.2		
Emerald Shiner							0.4	0.25
Gizzard Shad							0.45	0.45

B. Lipid Concentrations

Lipids (%)	Receptor							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	5.4	12.0	4.4	4.4	7.6	7.6	7.3	7.3
Mean Lipids for this	5.4	12.0		4.4		7.6		7.3
Mean Lipids over All	5.6	7.3		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.011	0.015	
Sediment (I_d)	3,699	3,749	14

Table 7-3 Inputs to the FRFood Model for Model Calibration in Little Rapids to De Pere Reach

A. Diet

Prey	Receptors							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
	Muth & Busch, 1989	Muth & Busch, 1989; Kolok *et al.* ,	Carlander, 1997a; Scott & Crossman,	Carlander, 1997a	Weber & Otis, 1984	Scott & Crossman, 1973	Carlander, 1997b; Wolfert & Bur,	Wolfert & Bur, 1992; Magnuson & Smith,
Phytoplankton	0.7	0.7		0.3	0.3			0.1
Zooplankton	0.2	0.3	0.9	0.4	0.4	0.45	0.05	
Chironomids	0.1		0.1	0.3	0.3	0.35	0.1	0.2
Oligochaetes						0.2		
Emerald Shiner							0.4	0.25
Gizzard Shad							0.45	0.45

B. Lipid Concentrations

Lipids (%)	Receptor							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	7.0	2.8	2.2	2.2	6.9	6.9	8.1	8.1
Mean Lipids for this	7.0	2.8		2.2		6.9		8.1
Mean Lipids over All	5.6	7.3		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.011	0.012	
Sediment (I_d)	2,078	2,112	5.3

Table 7-4 Inputs to the FRFood Model for Model Calibration in Green Bay Zone 1

A. Diet

Prey	Receptors										
	Rainbow Smelt Mills *et al.*, 1995	Gizzard Shad * Muth & Busch, 1989;	Shiner Species Muth & Busch, 1989	Alewife YOY Hewett & Stewart, 1989;	Alewife Adult Hewett & Stewart, 1989	Yellow Perch YOY Carlander, 1997a; Scott & Crossman,	Yellow Perch Adult Carlander, 1997a	Carp YOY Weber & Otis, 1984	Carp Adult Scott & Crossman, 1973	Walleye YOY Carlander, 1997b; Wolfert & Bur,	Walleye Adult Wolfert & Bur, 1992; Magnuson & Smith,
Phytoplankton		0.3	0.6				0.3	0.3			
Zooplankton	0.9	0.6	0.3	1	0.95	0.9	0.4	0.4	0.45	0.05	
Chironomids		0.1	0.1		0.05	0.1	0.3	0.3	0.35	0.3	0.1
Oligochaetes									0.2		
Yellow Perch YOY											
Alewife YOY	0.1									0.15	
Alewife adult											0.1
Rainbow Smelt										0.1	0.1
Emerald Shiner											
Gizzard Shad										0.4	0.7

B. Lipid Concentrations

Prey	Receptor										
	Rainbow Smelt	Gizzard Shad	Shiner Species	Alewife YOY	Alewife Adult	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	4.6 *	7.1	6	5.7	5.7	4.5	4.5	9.2	9.2	10.7	10.7
Mean Lipids for this	4.6 *	7.1	5.6/6.1		5.7		4.5		9.2		10.7
Mean Lipids over All	4.6	7.3	5.6		8.6		3.4		10.1		9.7

Note:
* Zone 2 average; rainbow smelt were not caught in Zone 1.

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.017	0.018	
Sediment (I_d)	2,959	2,984	5

Table 7-5 Inputs to the FRFood Model for Model Calibration in Green Bay Zone 2

A. Diet

Prey	Receptors										
	Rainbow Smelt Mills *et al.*, 1995	Gizzard Shad * Muth & Busch, 1989;	Shiner Species Muth & Busch, 1989	Alewife YOY Hewett & Stewart, 1989;	Alewife Adult Hewett & Stewart, 1989	Yellow Perch YOY Carlander, 1997a; Scott & Crossman,	Yellow Perch Adult Carlander, 1997a	Carp YOY Weber & Otis, 1984	Carp Adult Scott & Crossman, 1973	Walleye YOY Carlander, 1997b; Wolfert & Bur,	Walleye Adult Wolfert & Bur, 1992; Magnuson & Smith,
Phytoplankton		0.3	0.6				0.3	0.3			
Zooplankton	0.9	0.6	0.3	1	0.95	0.9	0.4	0.4	0.45	0.05	
Chironomids		0.1	0.1		0.05	0.1	0.3	0.3	0.35	0.3	0.1
Oligochaetes									0.2		
Yellow Perch YOY											
Alewife YOY	0.1									0.15	
Alewife adult											0.1
Rainbow Smelt										0.1	0.1
Emerald Shiner											
Gizzard Shad										0.4	0.7

B. Lipid Concentrations

Prey	Receptor										
	Rainbow Smelt	Gizzard Shad	Shiner Species	Alewife YOY	Alewife Adult	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	4.6	6.9	6	9.8	9.8	3.2	3.2	11.3	11.3	10.4	10.4
Mean Lipids for this Reach	4.6	6.9	—	—	9.8	—	3.2	—	11.3	—	10.4
Mean Lipids over All Areas	4.6	7.3	5.6		8.6		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.0048	0.0054	
Sediment (I_d)	1,132	1,154	1.5

Table 7-6 Lower Fox River Bioaccumulation Model Calibration

Location	Species	Number of Samples	Number of Detects	Detection Frequency	Observed Total PCB Mean	Observed Total PCB 95% UCL		Predicted Total PCB Mean	Predicted Total PCB 95% UCL	Units
Little Lake Butte des Morts										
	Water (filtered)	46	40	87	**0.011**	**0.015**				μg/L
	Surface Sediments (N)	302	294	97	10,724	22,848				μg/kg
	Surface Sediments (I_0)	57,724	57,724	100	3,284	3,330				μg/kg
	Surface Sediments (I_d)	51,261	51,261	100	**3,699**	**3,749**				μg/kg
	Gizzard Shad	4	4	100	296	530	*	263	358	μg/kg
	Golden Shiner	2	2	100	993	1,140	*	723	868	μg/kg
	Yellow Perch	1	1	100	363	363	*	1,266	1,443	μg/kg
	Carp	30	30	100	1,992	2,957		2,374	2,639	μg/kg
	Walleye	13	11	85	1,159	3,800	*	1,756	2,109	μg/kg
Little Rapids to DePere										
	Water (filtered)	98	97	99	**0.011**	**0.012**				μg/L
	Surface Sediments (N)	209	203	97	4,782	10,543				μg/kg
	Surface Sediments (I_0)	37,490	37,490	100	2,054	2,088				μg/kg
	Surface Sediments (I_d)	37,060	37,060	100	**2,078**	**2,112**				μg/kg
	Gizzard Shad	3	3	100	347	370	*	318	347	ug/kg
	Golden Shiner	2	2	100	1,020	1,036	*	997	1,046	ug/kg
	Yellow Perch	1	1	100	627	627	*	1,017	1,055	μg/kg
	Carp	20	20	100	3,919	5,800		3,038	3,135	μg/kg
	Walleye	4	4	100	3,179	4,587	*	3,881	4,079	μg/kg

Table 7-6 Lower Fox River Bioaccumulation Model Calibration (Continued)

Location	Species	Number of Samples	Number of Detects	Detection Frequency	Observed Total PCB Mean	Observed Total PCB 95% UCL		Predicted Total PCB Mean	Predicted Total PCB 95% UCL	Units
Green Bay Zone 1										
	Water (filtered)	143	142	99	**0.017**	**0.018**				μg/L
	Surface Sediments (N)	290	285	98	4,184	5,510				μg/kg
	Surface Sediments (I_0)	52,115	52,115	100	2,950	2,976				μg/kg
	Surface Sediments (I_d)	51,963	51,963	100	**2,959**	**2,984**				μg/kg
	Alewife	13	13	100	2,596	3,018		1,491	1,566	μg/kg
	Gizzard Shad	18	18	100	2,017	2,369		1,560	1,613	μg/kg
	Common Shiner	5	5	100	3,520	3,846		1,572	1,636	μg/kg
	Emerald Shiner	5	5	100	3,520	3,846		1,572	1,636	μg/kg
	Golden Shiner	2	2	100	1,385	1,443	*	1,572	1,636	μg/kg
	Yellow Perch	5	5	100	1,435	2,005		2,552	2,610	μg/kg
	Carp	66	66	100	7,203	8,286		5,352	5,454	μg/kg
	Walleye	51	51	100	6,902	8,414		9,091	9,419	μg/kg
Green Bay Zone 2										
	Water (filtered)	63	63	100	**0.0048**	**0.0054**				μg/L
	Surface Sediments (N)	15	14	93	251	5,510				μg/kg
	Surface Sediments (I_0)	11,713	11,713	100	1,117	2,976				μg/kg
	Surface Sediments (I_d)	11,566	11,566	100	**1,132**	**2,984**				μg/kg
	Alewife	38	38	100	2,600	3,374		923	992	μg/kg
	Gizzard Shad	32	32	100	1,759	1,906		1,184	1,230	μg/kg
	Rainbow Smelt	33	33	100	1,049	1,152		410	462	μg/kg
	Yellow Perch	4	4	100	920	1,637	*	2,028	2,084	μg/kg
	Carp	49	49	100	5,875	8,914		6,267	6,425	μg/kg
	Walleye	40	40	100	6,076	6,790		6,473	6,750	μg/kg

Notes:

Boxed and bolded values represent sediment inputs to the Lower Fox River bioaccumulation model.

* Maximum concentration and not the 95% UCL.

Table 7-7 Reach-specific and River-wide Total PCB Water-to-Sediment Ratios

Location	Media	Year	Minimum	Maximum	Average
Little Lake Butte des Morts	Sediment	1989	25	130,000	13,535
Little Lake Butte des Morts	Water	1989/90	0.0015	0.0592	0.0276
Water-to-sediment Ratio			6.00E-05	4.55E-07	2.04E-06
Appleton to Little Rapids	Sediment	1989	50	57000	3,651
Appleton to Little Rapids	Water	1989/90	0.00004	0.0710	0.0168
Water-to-sediment Ratio			8.00E-07	1.25E-06	4.60E-06
Little Rapids to De Pere	Sediment	1989	80	33,000	3,873
Little Rapids to De Pere	Water	1989/90	0.0004	0.1240	0.0411
Water-to-sediment Ratio			5.00E-06	3.76E-06	1.06E-05
Green Bay Zone 1	Sediment	1989	20	18,700	2,700
Green Bay Zone 1	Water	1989/90	0.0038	0.1940	0.0609
Water-to-sediment Ratio			1.91E-04	1.04E-05	2.26E-05
Green Bay Zone 2					
Water-to-sediment Ratio		GBTOXe*	5.26E-07	2.43E-05	8.47E-06

Notes:

Water represents the estimated total PCB concentration.
Zone 2 sediment:water ratios estimated from GBTOXe output.
Concentrations in units of ppb.

Table 7-8 Ratio of PCB Concentrations in Fillet to Whole Body for Different Species

Study and Species	Fillet-to-whole Fish Ratio
Lower Fox River	
Walleye	0.17
Carp	0.53*
Perch	0.17
White Bass	0.44
White Sucker	0.48
Parkerton (1993)	
Perch	0.04 *
Walleye	0.1 *
Bevelhimer et al. (1997)	
Black Bass	0.43
Amhreim et al. (1999)	
Coho Salmon	0.59
Rainbow Trout	0.68
Niimi and Oliver (1983)	
Rainbow Trout	0.34
Connolly (1991)	
Flounder	0.18
Connolly et al. (1992)	
Brown Trout	1
Brown Trout	0.88
Brown Trout	0.57
Coho Salmon	0.89
Walleye adult	0.09
Channel Catfish	0.59
Drum	0.32
Perch	0.04

Notes:

CPCB-f - Concentration of PCB in fish fillet.

CPCB-wb - Concentration of PCB in whole body of fish.

* Fillet-to-whole body ratios selected.

Table 7-9 Sediment Quality Thresholds Estimated for Human Health Effects at a 10^{-5} Cancer Risk and Noncancer Hazard Index of 1.0

	Fish Parameters	Sediment Quality Thresholds			
	Fillet-to-whole Fish Ratio	Recreational Anglers: (West *et al.*, 1989; West, 1993)		High-intake Fish Consumers: (West, 1993; Hutchison and Kraft, 1994)	
		RME µg/kg	CTE µg/kg	RME µg/kg	CTE µg/kg
Sediment Quality Thresholds for Risk of 10^{-5} *					
Carp	0.53	***16***	***180***	***11***	***57***
Walleye	0.17	***21***	***143***	***14***	***75***
Yellow Perch	0.17	***105***	***677***	***68***	***356***
Sediment Quality Thresholds for HI of 1.0					
Carp	0.53	***44***	***180***	***28***	***90***
Walleye	0.17	***58***	***238***	***37***	***119***
Yellow Perch	0.17	***276***	***1,128***	***175***	***564***

Notes:

* ***SQTs for cancer risks of 10^{-4} and 10^{-6} are an order of magnitude higher, and lower, respectively.***

RME indicates reasonable maximum exposure and CTE indicates central tendency exposure.

Sediment Quality Thresholds are **bolded** and in *italics*.

Table 7-10 Derivation of Bird Biomagnification Factors (BMFs) for Total PCBs

Location	Bird Species	Bird Tissue	Total PCB (µg/kg) RME	Fish Species	Fish Tissue	Total PCB (µg/kg) RME	BMF RME
Appleton to Little Rapids	Bald Eagle	egg	36,000	carp	whole	3,606	9.98
Zone 2	Double-crested Cormorant	egg	21,127	alewife	whole	3,182	6.64
Zone 2	Double-crested Cormorant	whole	13,870	alewife	whole	3,182	4.36
Zone 2	Common Tern	egg	5,963	alewife	whole	3,182	1.87
Zone 2	Forster's Tern	egg	6,234	alewife	whole	3,182	1.96
Zone 3B	Double-crested Cormorant	whole	15,000	alewife	whole	2,375	6.32
Zone 3A	Bald Eagle	egg	13,000	carp	whole	3,974	3.27

Species	RME BMF	TRVs Reproduction NOAEC (µg/kg)	TRVs Reproduction LOAEC (µg/kg)	TRVs Deformity NOAEC (µg/kg)	TRVs Deformity LOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Reproduction NOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Reproduction LOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Deformity NOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Deformity LOAEC (µg/kg)
Common Tern	1.87	4,700	7,600	800	8,000	2,508	4,055	427	4,269
Forster's Tern	1.96	4,700	7,600	800	8,000	2,399	3,879	408	4,083
Double-crested Cormorant	5.77	4,700	7,600	800	8,000	814	1,317	139	1,386
Bald Eagle	6.63	4,700	7,600	800	8,000	709	1,147	121	1,207

Table 7-11 Sediment Quality Thresholds Estimated for Ecological Effects

Species	Effect	Whole Fish Concentration (µg/kg ww)	Estimated SQT (µg/kg)
benthic invertebrates	Threshold Effect Concentration (TEL)	—	31.6
walleye	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	176 1,759
carp	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	363 3,633
common tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,508 4,055 427 4,269	3,073 4,969 523 5,231
Forster's tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,399 3,879 408 4,083	2,940 4,753 500 5,003
double-crested cormorant	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	814 1,317 139 1,386	997 1,614 170 1,698
bald eagle	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	709 1,147 121 1,207	339 548 58 577
mink	NOAEC - reproduction and kit survival LOAEC - reproduction and kit survival	50 500	24 239